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# A model for biodiesel supply chain: A case study in Iran

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ABSTRACT

Biodiesel is here considered as an alternative fuel in Iran in order to benefit from environmental aspects and contribution to final energy demand. An analytical tool is developed to consider different scenarios in biodiesel production. This study provides a regional framework in terms of techno-economic parameters to deeply understand the agricultural, technical, and economic aspects of biodiesel supply chain of Iran including resources, production, distribution, and consumer. The study further assesses the potential of biodiesel production in different geographical regions of Iran. It reveals the contribution of current potential resources to make the future biodiesel demand.



**Contents**



## 1. Introduction

Reliable energy supply systems along with the environmental issues coming from excessive usage of fossil resources are the critical topics of interest recently. Biodiesel has been proposed as a sustainable fuel rather than an alternative [1]. It is successfully utilized for diesel engines [2]. Biomass accounted for approximately 10% of global primary energy consumption in 2007 while modern biomass, including biofuels, on-site heat, electricity and district heat globally contribute to 19 EJ in 2008 (cf. [3]). Moreover, the potential assessment of biomass productions often varies in the reviewed studies depending on the surplus availability of land. It differs from 33 EJ/yr in 2050 (cf. [4]) to 1500 EJ/yr in 2050 (cf. [5]).

Biofuel production could potentially play a major role in satisfying rapid growth of energy demand of Iran in near future [6]. Its energy demand is drastically increased during the last decade (cf. Fig. 1). On the other side, the rate of agricultural waste has recently raised in Iran while the efficient use of these wastes is currently very limited [7]. Thus, these motivations encourage the usage of wastes to produce energy in order to contribute in satisfying the final energy demand.

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**Nomenclature**

| | |
|---|---|
| $Al_{tie\tau}$ | land area of technology type $\tau$ for energy carrier $e$ in region $i$, ha |
| $Al_{\max,tie\tau}$ | maximum land available to be utilized |
| $co_{ltie\tau}$ | operating cost per flow of energy carrier $e$ from technology $\tau$ in region $i$ at time $t$ in level $l$ |
| $cc_{ltie\tau}$ | capital cost of technology type $\tau$ for energy carrier $e$ in region $i$ at time $t$ in level $l$ |
| $CF_{tie\tau}$ | land capacity production, t/ha |
| $Dl_{tie\tau}$ | average land degradation factor in time $t$ and region $i$ for energy carrier $e$ and technology type $\tau$ |
| $h$ | harvest residue generation fraction |
| $hr$ | harvest residue recoverability fraction |
| $HI$ | harvest index |
| $X_{ltie}$ | flow in level $l$ at time $t$ in region $i$ for carrier $e$ |
| $OC_{lt\tau}$ | operating cost of technology type $\tau$ in level $l$ at time $t$ |
| $CC_{lt\tau}$ | capital cost of technology type $\tau$ in level $l$ at time $t$ |
| $pc_{tie\tau}$ | potential of cultivation for energy carrier $e$ in region $i$ for technology type $\tau$ |
| $r$ | discount rate |
| $Y$ | capacity |

*Greek symbols*

| | |
|---|---|
| $\eta$ | technology efficiency in each level |
| $\tau$ | subscript for technology type $\tau$ |

*Subscripts*

| | |
|---|---|
| $A$ | level of end products |
| $B$ | level of distribution |
| $C$ | level of conversion |
| $D$ | level of transport |
| $e$ | subscript for energy carrier |
| $E$ | level of supply systems |
| $F$ | level of resources |
| $HC$ | historical capacity |
| $i,j,k$ | subscript for region |
| $l$ | subscript for level |
| $lt$ | life time of each technology |
| $t$ | time horizon $t = 1, \ldots, T$. |
| $up$ | upper bound on variables |
| $yr$ | time point |

Ghobadian et al. [9] reviewed the development activities and policies of main renewables in Iran involving wind, geothermal, solar, and biomass. However, little work has been done on the bioenergies. Taleghan site could only provide the energy for direct use in hydrogen supply chain energy [9]. Hamzeh et al. [10] also studied the production potential of biomass from wastes in Iran. They reported the annual biomass production of $8.78 \times 10^6$, $7.7 \times 10^6$, and $3 \times 10^6$ tonnes from agriculture, animal, and municipal wastes, respectively. Ghobadian et al. [9] studied the potential of bioethanol as promising alternatives to use in transportation sector of Iran in order to reduce the import of gasoline as well as benefit environmental effects. They reported the production potential of 4.91 GL of bioethanol from the wasted crops such as wheat, sugar cane, rice, barely, corn, potato, date, sugar beet, grape, and apple annually. Recently, Saffieddin Ardebili et al. [11] reported the annual potential of 721 million liter of biodiesel from different available oils seeds in Iran. The rapeseed, cotton, and soybean are the most favorable oil seeds which may be grown in North of Iran as the most promising area for planting.

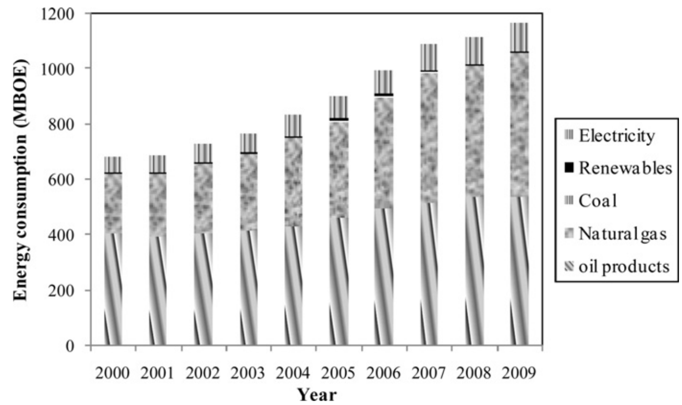


**Fig. 1.** Energy consumption in Iran during 2000–2009 [8].

It is currently expected that 2% of Iranian diesel demand can be ideally replaced from agricultural wastes [11]. The advantages are (1) reducing the green house emissions, (2) contributing to total energy demand in Iran especially in the transport sector, (3) increasing the security of energy network in transport sector and as a consequent reducing the dependency on different fuel imports, (4) increasing rural development. Hence, design of sustainable biodiesel network in Iran is a complex multi-criteria planning problem with socio-economic consequences. However, there is not a comprehensive study on potentially available biodiesel resources in Iran.

Therefore, there is a substantial need to study the whole supply chain of biodiesel (from farms to consumers) to evaluate the socio-economic impacts as well as understanding the substantial factors in determining the optimal path to the development of biodiesel plans and supporting strategies in Iran. Such studies are usually regionally based into energy, economic, environmental, and social impacts of biodiesel production, conversion, and consumption. This work presents a model to determine an optimal biodiesel pathway of Iran in different regions considering the potential of cultivation in each geographic area, the regional economies, and technical aspects of the supply chain. An important aspect of the current work is integrating the detailed models of agriculture sector and conversion plants into the supply chain regarding regional limitations. The model enables the selection of conversion plants, capacities, the logistics of transportation, and the location of farms. The model uses the realistic available data for Iran.

Therefore, Section 2 reviews briefly the current supply models of renewable energies. Section 3 describes the current methodology to provide the optimal pathway for biodiesel network in Iran. Section 4 gives the results under different scenarios regarding critical concerns of the supply system in Iran. Section 5 concludes the paper and gives recommendations, general proposed policies, and future works.

## 2. An overview of the renewable energy models

Modeling the supply system of renewable energies has recently received a lot of attentions. Sylvain et al. [12] presented a linear model to determine the geographical locations of methanol plants in Austria regarding the costs of harvesting, transportation, production, and handling. Qadrdan et al. [13] proposed a linear dynamic model to model hydrogen supply system in Iran including biomass. Parker et al. [14] used a nonlinear programming model to determine the optimal green hydrogen pathway from agricultural residues. Therefore, all activities (harvesting, conversion, and distribution) must be taken into account in a cost effective optimized

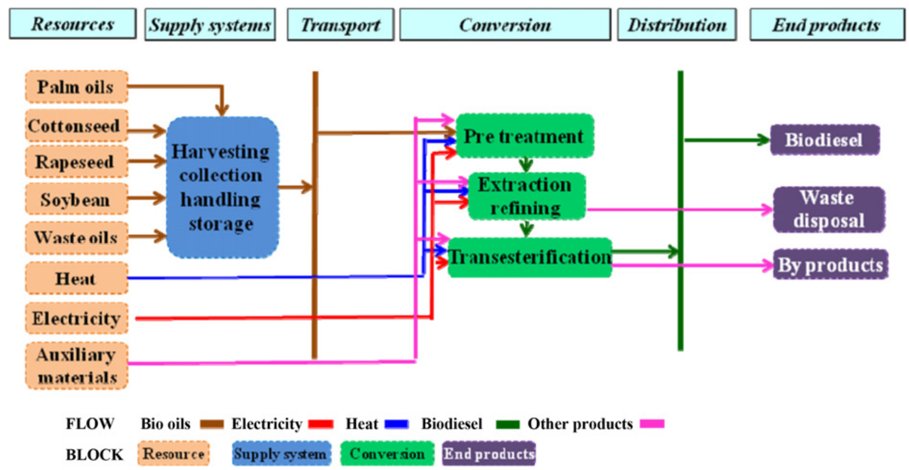


**Fig. 2.** Illustration of reference supply chain model for biodiesel in Iran.

supply chain model. Most supply chain models were considered from economical aspect [15,16].

A number of studies have previously been performed to analyze different aspects of biodiesel energy system [17–20]. Different assumptions are made in their works concerning the feedstock sources, technologies, cost of units, and distribution systems. The modeling strategies can be classified from different aspects such as static vs. dynamic, centralized vs. decentralized network, deterministic vs. uncertain modeling, time horizon, geographical dimension, and diversity of feedstock. A further study on different energy supply systems may be found by Bhattacharyya et al. [21].

For sustainable integration of biodiesel supply chain, much attention is focused on taking into account the agriculture section into the whole supply model. Another aspect is about the regional concerns. In this work, a mathematical programming model is proposed for the supply chain of biodiesel in Iran. A detailed formulation of each section from the resource level to the end user is considered to cover regional issues. Since the model finds the optimal location of plants and farms by simultaneous optimization considering distribution costs, different trades off may be studied. The model also focuses on the integration of the units in order to operate the whole supply system efficiently in Iran. The capabilities of the proposed model are highlighted by application of different scenarios in Section 4. The model proposes an efficient analytical tool to study the behavior of the biodiesel supply chain in Iran which potentially requires less time to operate.

## 3. Methodology

The framework to regionally supply chain model of biodiesel is presented in this section. The model encompasses the complex interactions between various biodiesel feedstock sources, conversion technologies, energy yield, geographical diversity, supply and demand, economics, and availability constraints on sources over the temporal scale. The supply system for biodiesel consisting different levels, various technologies in each level, and energy demand is depicted in Fig. 2. Each chain consists of six levels: resources, supply system, transport, conversion, distribution, and demand. Different agricultural feed stocks are the main contributor to produce bio energy in Iran [10]. However, the oil content and the potential of cultivation may vary. Rapeseed, cotton, and soybean are the most favorable oil seeds to produce biodiesel in Iran [11]. More seed crops are here considered as potential resources to produce biodiesel. The energy potential of crops depends on the type of technology to harvest, process as well as collect the crops. These parameters are taken into account in supply system level in Fig. 2. Furthermore, three different processes are considered in the conversion level: homogeneous alkaline catalyst with acid preesterification, homogeneous acid catalyst, and heterogeneous solid catalyst along with the pretreatment and extraction units. The produced biodiesel from the conversion level will be then distributed in the whole country to reach to the consumers in different geographical regions. The present techno-economic biodiesel supply chain determines the optimal flows in each level, the optimal required capacities, and the optimal biomass supply systems regarding the constraints in farms, along with the economic costs (operating and capital) of different scenarios for Iran. The model represents the optimal flows of energy in supply chain. The mathematical formulation of supply chain, depicted in Fig. 2, is described in the following. The balances and relevant constraints ensure that the model will satisfy the demand which is an exogenous parameter provided by the user.

### 3.1. Level of resources

Considering the potential of cultivation and production of capacity of lands in different geographical regions, the flow of bio carriers for specified planting technology are then described by

$$X_{Ftie} = \sum_{\tau_F=1}^{k} CF_{tie\tau} \cdot pc_{tie\tau} \cdot Al_{tie\tau}, \tag{1}$$

where $CF$ is the land capacity production of region $i$ for energy carrier $e$ with technology type $\tau$, $pc$ is a binary parameter describing the potential capacity of each region to cultivate specific bio oil, and $Al$ is the land area. The sum of all bioenergy flows from different crops cannot exceed the maximum land available for harvesting in each region at specified year which is announced by agriculture ministry. Thus one more equation is added to satisfy capacity constraint as well as describe the required land capacity regarding land degradation and crop rotation. The equation is considered in order to improve the performance of farms, protect soil and water and improve the economy of harvesting and it is given by

$$Al_{tie\tau} \le \sum_{e}\sum_{\tau} pc_{tie\tau} \cdot Al_{\max,tie\tau} - \sum_{yr=t-rp}^{t} Al_{yrie\tau}. \tag{2}$$

### 3.2. Level of supply systems

The availability of residues from the feedstock is dependent on variables such as the crop species, the type of technology for

harvesting, the other usage of crops, and the conditions of harvesting. The potential of bioenergy from farms is calculated from the methodology presented by Smeets et al. [5]. The formulation is given by

$$X_{Etie\tau} = X_{Ftie\tau} \cdot \eta_{Etie\tau}, \tag{3}$$

$$\eta_{Etie\tau} = h_{tie} \cdot hr_{tie} \tag{4}$$

$$h_{tie} = \frac{1}{HI_{tie}} - 1, \tag{5}$$

where $\eta$ is the technology efficiency in level $E$, $h$ the harvest residue generation fraction (i.e. the ratio of the amounts of residues generated to the amount harvested), $hr$ the harvest residue recoverability fraction (i.e. the fraction of the harvest residue that can be recovered actually), and $HI$ the harvest index (i.e. the ratio of the part of crops harvested to the total crops on the ground). The coefficients are taken from Smeets et al. [5].

### 3.3. Conversion level

The mass balances must be satisfied at each conversion plant. Eq. (6) is the flow balance in each region for specified conversion technology. It states that the outward flows from each conversion technology are equal to the inward flows of bioenergy from each crop multiplied by its corresponding efficiency.

$$X_{Ctie\tau} = X_{Dtie\tau} \cdot \eta_{Ctie\tau}. \tag{6}$$

The sum of all bioenergies coming from different sources cannot exceed the historical capacity of chosen plant regarding its life time. In addition to historical capacities, the model may determine the new required capacities to be installed in order to satisfy the final demand each year. The availability constraint is then represented by

$$X_{Ctie\tau} = \sum_{yr<t, yr<lt} Y_{HC,yr} + Y_{new,t}. \tag{7}$$

### 3.4. Transport/distribution level

The equations for transport/distribution levels are taken from Qadrdan et al. [13]. Eq. (8) states that the sum of energy carriers $e$ from conversion level to transport technology $\tau$ (which delivers the energy carrier $e$ from region $i$ to region $j$) multiplied by its efficiency $\eta$ and the sum of energy carrier $e$ coming from transport network in other regions are equal to the net energy carrier $e$ delivered to end product users in each region. Since the model is used to forecast the status of biodiesel supply chain annually, the seasonal storage is not considered in this formulation.

$$\sum_i \sum_\tau X_{Btije\tau} \cdot \eta_{Btije\tau} - \sum_k \sum_\tau X_{Btike\tau} - X_{Atie} = 0. \tag{8}$$

### 3.5. Level of end products

The balance of supply and demand is considered as follows

$$X_{Atie} \geq D_{ti}. \tag{9}$$

### 3.6. Objective function

The objective function is to minimize the total discounted costs of the supply chain. It involves the operating cost of whole supply system and the annualized capital costs of chosen capacity for each technology. The costs are calculated from Eqs. (11) and (12).

$$TAC = \sum_{t=1}^{T} \sum_l \sum_\tau \left[ \frac{OC_{lt\tau}}{(1+r)^t} + \frac{CC_{lt\tau}}{(1+r)^t} \right]. \tag{10}$$

$$OC_{lt\tau} = \sum_i \sum_e co_{ltie\tau} \cdot X_{ltie\tau}. \tag{11}$$

$$CC_{lt\tau} = \sum_i \sum_e cc_{ltie\tau} \cdot Y_{ltie\tau}. \tag{12}$$

**Table 1**
Geographical dimension of the model.

| Region | Name of relevant states |
|---|---|
| A | Azarbayjan-e-sharqi, Azarbayjan-e-Gharbi, Ardebil, Gilan, Zanjan |
| B | Tehran, Qom, Qazvin, Markazi |
| C | Mazandaran, Golestan, Semnan |
| D | Khorasan-e-shomali, Khorasan-e-jonubi, Khorasan-e-razavi |
| E | Kordestan, Kermanshah, Ilam, Lorestan, Hamedan |
| F | Esfahan, Chaharmahal and Bakhtiary, Yazd |
| G | Khozestan |
| H | Fars, Kohkiluyeh and Boyerahmad, Bushehr |
| I | Hormozgan |
| J | Kerman, Sistan and Baluchestan |

The model integrates the detailed descriptions of agriculture sector and industrial conversion plants into the whole supply chain model in order to simultaneously minimize the costs. The general mathematical formulation is represented as follows

$$\begin{aligned} &\text{Minimize} \quad TAC \\ &\text{s.t.} \\ &\quad \text{Eqs. } (1)\text{–}(9), \\ &\quad X \leq X_{up}, \\ &\quad Y \leq Y_{up}, \\ &\quad \cos t \leq \cos t_{up}. \end{aligned} \tag{13}$$

The input parameters for the problem are the biodiesel demand, costs, geographical data, technical data of each technology, and agriculture data. The objective is to determine the optimal investment and optimal pathway to satisfy biodiesel demand. This formulation provides an analytical tool to study the biodiesel chain in Iran for energy planners and decision makers.

Not that the country is divided into ten regions which enable us to satisfy the regional demand and find the regional bioenergy resources. These regions are listed in Table 1. Since there is not sufficient pipeline and railroad available for biodiesel transportation in the country and the existing pipeline network cannot be used due to the operational constraints, it is transported by trucks. The biodiesel is produced or delivered in the demand centers of each region and each region is therefore considered as a node. Moreover, the structure of the model also allows considerations for additional chains such as bioenergy from algae. This point is further discussed in Section 3.3.

## 4. Results and discussion

Scenarios are designed based on the necessities of decision makers and planners. In general, they analyze the critical issues on the supply chain system. In this work, the following assumptions are considered in the reference scenario:

(a) Transportation/distribution levels are closed and there is no trade-off to import and export biodiesel.

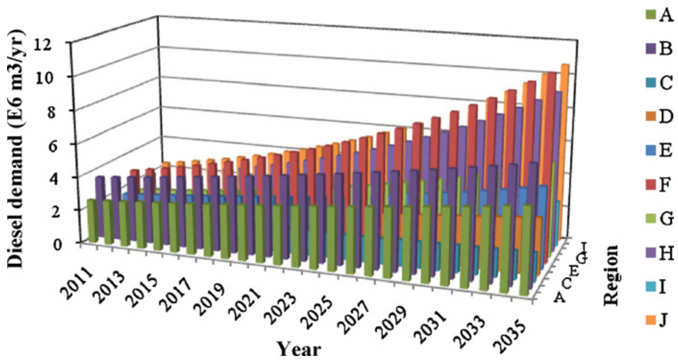


**Fig. 3.** Regional diesel demand over 25 years (between 2011 and 2035).

(b) The production plants are considered on-farm to avoid additional costs for transportation of feed stock.
(c) B2 and B5 (2% and 5% of biodiesel in the blend) options are considered as the two scenarios for demand over 25 years starting from 2011. The annual increase of diesel demand is calculated based on the average increase of consumption in last decade. The regional diesel demand is depicted in Fig. 3.
(d) The produced biodiesel meets the quality of ASTM standard.

The model specifications are defined and the techno-economic characteristic' are then fed to the model taken from actual data of Iran and international studies. In this study, the cost and technical information of agriculture section (resource level) are taken from agricultural ministry. The economical and technical parameters of conversion level are available by Marchetti et al. [22]. Also, the operating cost of technologies in distribution level is taken from Energy Balance of Iran [8] while other required parameters are available by Sadeghi and Hosseini [23]. Since the amount of maximum land area (actual data is taken from agriculture ministry which is given in Table A.1) for each geographical region is lower that the total cultivated land, the effect of land degradation and crop rotation is not taken into account in the reference scenario. It is further explained in Section 3.1. The seeds are mainly cultivated in irrigated or rainfed farms. Their share is specified to the model from the historical data provided by agriculture ministry which is given in Table A.2. Based on the above mentioned characteristics', the optimal supply pathway is determined for the reference scenario. The present value of the whole cost of supply chain for the reference scenario (B2) is 2.039E10$. The optimal results of different scenarios are described in Table 2.The optimal land area allocation of different oil seeds are also plotted in Figs. 4–7.

The annual land allocation of reference scenario (B2) is illustrated in Fig. 8 which is mainly dominated by rapeseed farms. In

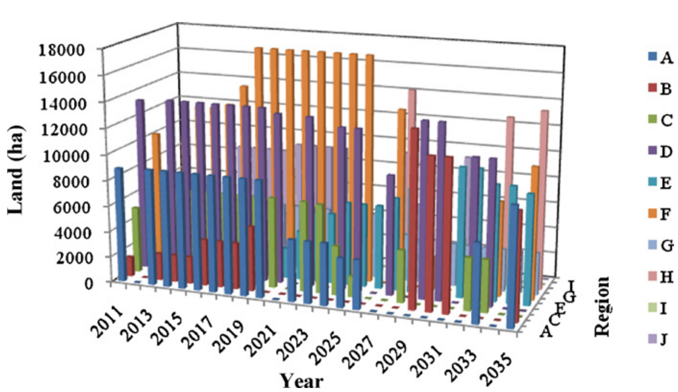


**Fig. 4.** Optimal land area allocation of rapeseed in different geographical regions (reference scenario B2).

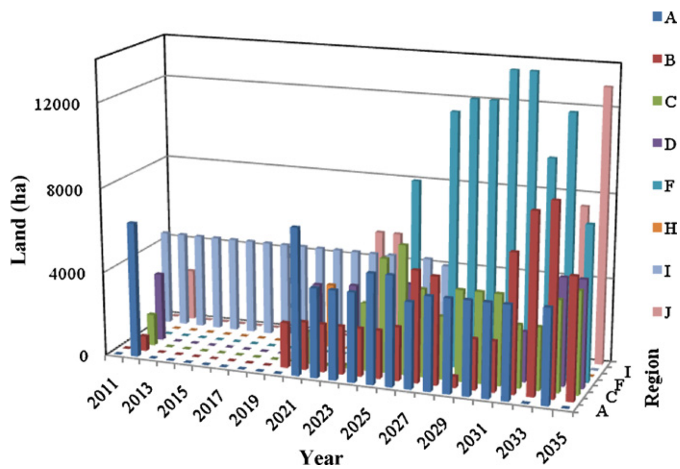


**Fig. 5.** Optimal land area allocation of cotton seed in different geographical regions (reference scenario B2).

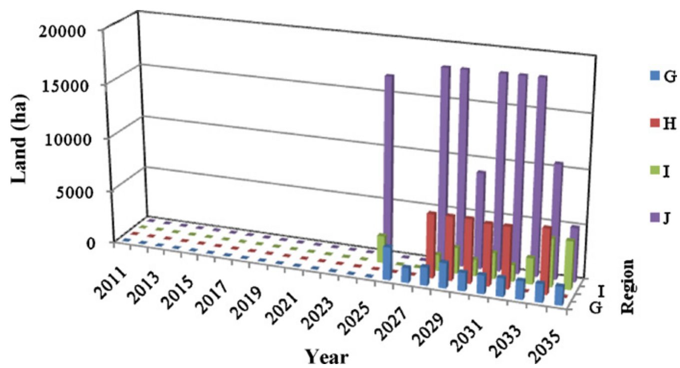


**Fig. 6.** Optimal land area allocation of palm oil in different geographical regions (reference scenario B2).

early years of prediction, rapeseed, soybean, and cotton seed are the bio energy sources while palm oil is an economical alternative at cultivated areas after 15 years. It is well depicted in Fig. 6. Soybean is mainly cultivated in region E in the reference scenario B2 (cf. Fig. 7).

Since there are different blends of biodiesel to be utilized in transportation sector, the biodiesel demand has increased to meet 5% of regional diesel demand (B5) in this scenario. Other assumptions are the same as the reference scenario (B2). As expected, the total present cost reaches to the value of 5.23E10$ (more than two times of B2 demand). The optimal allocation of land areas is

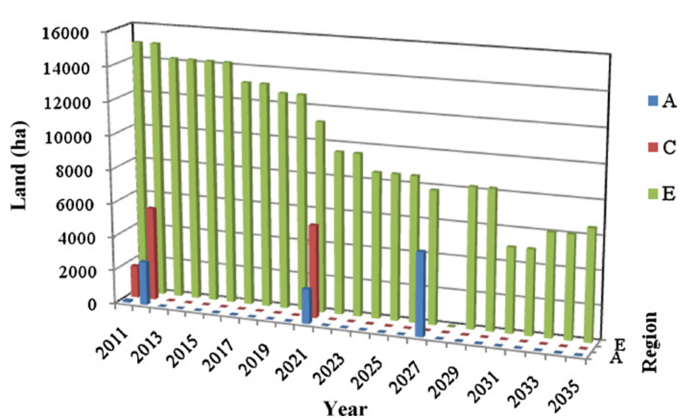


**Fig. 7.** Optimal land area allocation of soybean in different geographical regions (reference scenario B2).

**Table 2**
Optimal results of the model for different scenarios.

| Scenario | Specifications | Operating cost ($) | Capital cost ($) | Bioenergy resources |
|---|---|---|---|---|
| Reference scenario (B2) | B2 | 2.25E9 | 1.81E10 | Cotton seed, rapeseed, soybean, palm oil |
| Reference scenario (B5) | B5 | 7.08E9 | 4.53E10 | Cotton seed, rapeseed, soybean, palm oil |
| Scenario A (B2) | Crop rotation and land degradation. | 1.83E9 | 1.79E10 | Cotton seed, rapeseed, soybean, palm oil |
| Scenario B (B2) | Centralized network | 2.62E9 | 1.3E9 | Cotton seed, rapeseed, soybean, palm oil |
| Scenario C (B2) | Introducing algea as energy source | 3.2E9 | 1.92E10 | Cotton seed, rapeseed, soybean, palm oil, algea |

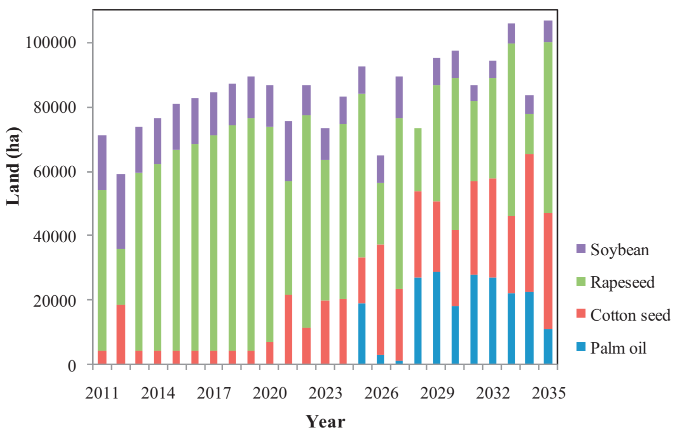


**Fig. 8.** Optimal land allocation for different bio energy seeds in Iran (reference scenario B2).

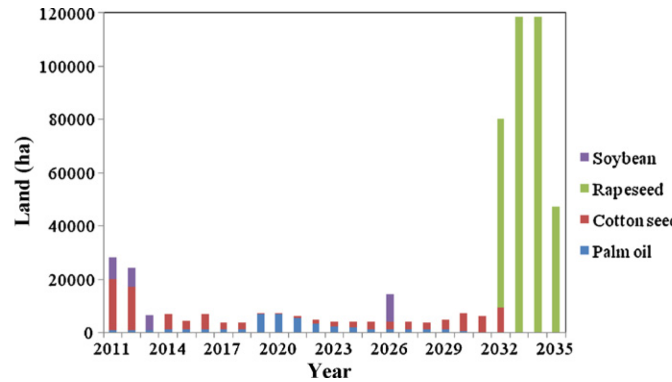


**Fig. 10.** Optimal land allocation of different bio oil seeds in scenario A (B2).

depicted in Figs. 8 and 9 for different bio energy seeds. This increase in biodiesel demand leads to an increase in the total cultivated areas. It reaches its maximum value in some specific regions after some years which guides us toward the usage of waste lands to satisfy higher demand values such as B5, B10, and more. Based on the actual techno-economical data obtained from Iranian farms, the model selects the cotton seed as major oil seed to satisfy the B5 final demand (cf. Fig. 9). Palm oil also has a significant contribution as bio energy source. Since palm oil is grown in southern parts of the country, its cultivation also affects environment positively which is of great importance to the country.

### *4.1. Agriculture sector (scenario A)*

The total land area of Iran is 162.2 million hectares in which 82.8% belongs to forests, grasslands, and deserts (cf. Agriculture ministry [24]). The residues are the lands under cultivations, urban, and lakes. One of the most critical aspects of land availability for bio oil cultivation is ownership, usufruct, and management. Their ownership belongs to agriculture sector and the values are reported in Appendix for better documentation. However, the total amount of available land suited for bio energy cultivation is much larger. Considering that the country has a large extent of wastelands, the focus on utilizing these wastelands for bio oil cultivation results in productive usage of waste lands too. Consequently, it has positive impacts on mitigation of desertification. Moreover, significant employment opportunities will be provided especially for rural areas. For these reasons, the usage of bio fuels is of great importance for Iranian energy sector. Land use and management in biofuel production are further discussed by Cowie et al. [25], Ravindranath et al. [26], and Cai et al. [27].

The effect of land degradation and crop rotation is here considered by taking into account the relevant time indexes in Eq. (2) in this scenario. The crop rotation for soybean and rapeseed is 3 years (cf. Agriculture ministry [24]). This value is assumed to be 1 year for cotton seed. In this model, the maximum available land is considered based on the recent information from agriculture ministry. The total cost of the supply chain in this scenario is equal to 1.97E10$. The results are depicted in Fig. 10. Palm oil is the prevailing oil seed resource in early years while rapeseed contributes significantly to satisfy biodiesel demand finally.

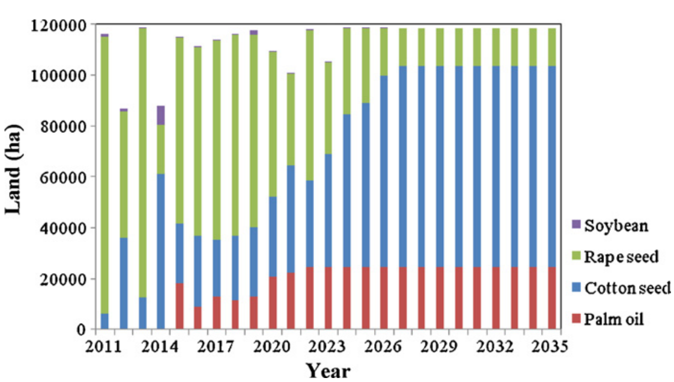


**Fig. 9.** Optimal land allocation for different bio energy seeds in Iran (reference scenario B5).

### *4.2. Centralized network system (scenario B)*

In terms of design of transportation network, one may take a distributed approach or centralized approach. The centralized approach refers to performing the conversion at the same region of the end product users. The advantages of the centralized network system include lower costs and easier management. However, the distributed approach provides more flexibility in satisfying the demand in all regions as well as increasing the security of the supply network. The trade-off could be analyzed depending on the local infrastructures such as resource availability, the amount of annual demand, and the cost of transportation.

In this scenario, total present cost of the centralized network is 3.92E9$. This indicates that biodiesel is produced at much lower cost in centralized network rather than the distributed approach (reference scenario B2). Also, the total land area allocation of different oil seeds is depicted in Fig. 11. Rapeseed and cotton seed are

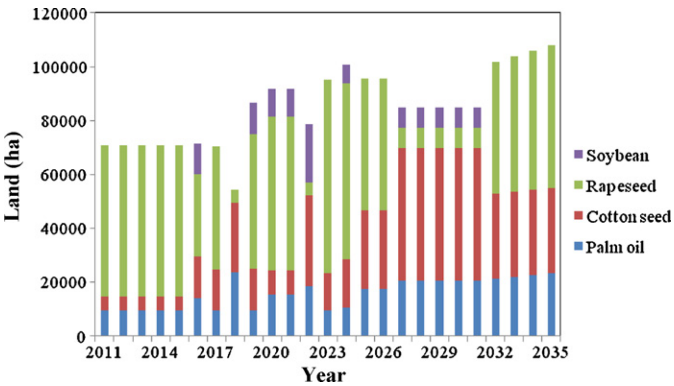


**Fig. 11.** Optimal land allocation of different bio oil seeds in scenario B (B2).

two main bio oil resources in early and final years of time horizon, respectively. Palm oil also contributes significantly in all years.

### *4.3. Algea as an energy source for biodiesel production (scenario C)*

The production of biofuels from food crops in order to substitute the oil-products reaches the goals of sustainable developments and climate change mitigation but it is limited by the competition for land and water [28,29]. In addition, high production costs require strategic planning for their developments in the country. Some aspects of land management are previously discussed in Section 3.1. In this context, the interests toward developing the biofuel plans from non-food crops are increased recently [30]. These feed stocks include forest residues, wastes, and other energy crops. Algea is the most promising non-food resource to produce bio fuels [31,32]. Recently, Najafi et al. present a description of the potential of utilization of algae oil to produce biodiesel in Iran focusing on the available resources [32]. Moreover, microalgea is studied as a candidate to produce biodiesel in Iran by Tabatabaei et al. [33]. Hence, the production of biofuels from microalgae (low oil content, 30%) in the whole supply chain of Iranian biodiesel is considered in this scenario. Photo bioreactors are essentially used to produce large quantities of algae biomass. Its techno-economic data is taken from Chisti [31]. The potential regions to produce algae are previously studied by Najafi et al. [32] which is used in this work. The total cost of the whole supply chain is 2.11E10$. It is then concluded that the algae is still economically feasible to the supply chain even though the costs are taken from international references. The optimal results of introducing algae as bio energy source in the supply chain are also depicted in Fig. 12.

On the whole, main challenging issues of introducing biodiesel in the final energy demand in Iran are studied in this work. As described in Table 2, the centralized network is the most economical scenario to produce biodiesel in Iran. However, special attention should be given to the land management and efficient usage of lands. Moreover, new bio oil resources such as algae have great potential to produce biodiesel in Iran.

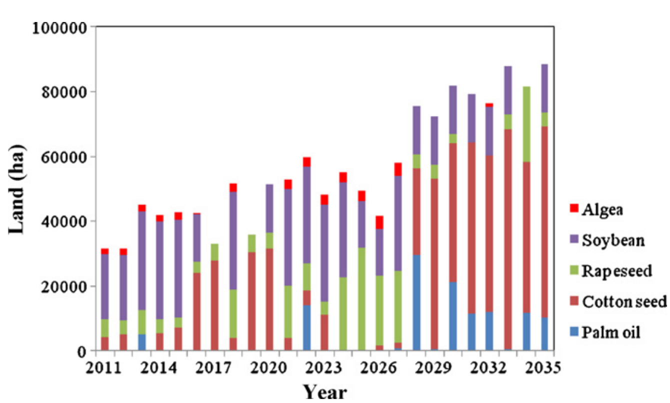


**Fig. 12.** Optimal land location for different bio energy sources in scenario C (B2).

## 5. Conclusion

Iran benefits renewable natural resources which may provide supplementary energy resources for partially substituting the fossil fuels. Furthermore, the rapid growth of waste production demands new policies. In this regard, this study provides a framework to assess the whole supply chain of biodiesel from resources to the end user. The opportunities are decreasing the green house emission, contribution of renewables to satisfy fuel demand, decreasing the amounts of fuels imported, increasing the security of fuel supply network, waste management, and providing the opportunity to utilize the fossil resources in more value-added products. It also provides some employment opportunities especially in rural areas. It has positive impact on the environment by mitigation of desertification.

The results obtained using this modeling approach provide some important policy insights regarding spatial dimension of the model. The model proposes the centralized network design with lower costs. It also suggests that land management issues affect the land allocations significantly which may improve the harvesting efficiency as well as protect land. Finally algae is economically feasible to produce biodiesel in Iran in certain areas.

Future works may be done to clarify the other aspects of biodiesel supply chain in Iran. The issues to be examined are as follows. The biodiesel from waste/cooking oils, fishes is another opportunity that may provide regional demands in certain areas. The feasibility needs further investigation in the framework of total supply chain of biodiesel network for Iran. The environmental effects should be evaluated by means of multi criteria decision-making. Beside the economy of the biodiesel, other strategic considerations should be taken into account to comprehensively study the opportunities and limitations for decision makers and planners.

## Disclaimer

This model in the present work is only used for research purposes. For specific applications please contact the author regarding the scope of the model.

## Appendix A. Regional data used in the present work

This appendix summarizes the actual data of Iran applied in different scenarios of the current model. These agriculture data are given in Tables A.1–A.3.

**Table A.1**
Maximum land in each geographical region, ha [24].

| Regions | Land (ha) |
|---|---|
| A | 9000 |
| B | 14,000 |
| C | 7000 |
| D | 13,500 |
| E | 15,000 |
| F | 17,500 |
| G | 5000 |
| H | 15,000 |
| I | 4500 |
| J | 18,000 |

**Table A.2**
Share of each planting technology for each specific region.

| Type of farms | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| Palm oil/irrigated | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.94 | 0.88 | 0.88 |
| Palm oil/rain-fed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0.12 | 0.12 |
| Cotton seed/irrigated | 1 | 1 | 0.9 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| Cotton seed/rain-fed | 0 | 0 | 0.1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Wheat germ/irrigated | 0.2 | 0.44 | 0.44 | 0.4 | 0.16 | 0.65 | 0.91 | 0.67 | 1 | 0.99 |
| Wheat germ/rain-fed | 0.8 | 0.56 | 0.56 | 0.6 | 0.84 | 0.35 | 0.09 | 0.33 | 0 | 0.01 |
| Rapeseed/irrigated | 0.99 | 1 | 0.28 | 1 | 0.83 | 1 | 0.52 | 1 | 1 | 1 |
| Rapeseed/rain-fed | 0.01 | 0 | 0.72 | 0 | 0.17 | 0 | 0.48 | 0 | 0 | 0 |
| Soybean/irrigated | 1 | 0 | 0.78 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Soybean/rain-fed | 0 | 0 | 0.22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table A.3**
Land production capacity of each specific region, kg/ha [24].

| Type of farms | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| Palm oil/irrigated | 0 | 0 | 0 | 0 | 0 | 0 | 5633.8 | 9311.7 | 4717.1 | 1088.5 |
| Palm oil/rain-fed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2991.9 | 2279.1 | 2850.7 |
| Cotton seed/irrigated | 5968.05 | 11,737.36 | 6630.48 | 7558.19 | 0 | 5026.44 | 0 | 2825.77 | 1338.89 | 2199.6 |
| Cotton seed/rain-fed | 0 | 0 | 1990.77 | 0 | 0 | 0 | 3000.27 | 0 | 0 | 0 |
| Wheat germ/irrigated | 18,171.73 | 18,539.27 | 11,633.6 | 10,006.1 | 20,166.78 | 11,564.35 | 686.29 | 9138.07 | 4084.62 | 5853.16 |
| Wheat germ/rain-fed | 5671.81 | 3561.01 | 7072.2 | 2115.48 | 5119.83 | 2489.61 | 1080.53 | 1791.77 | 0 | 2971.43 |
| Rapeseed/irrigated | 9209.16 | 8271.59 | 6068.15 | 3784.29 | 8531.82 | 5113.2 | 522.88 | 4398.03 | 1452.68 | 2684.06 |
| Rapeseed/rain-fed | 2779.07 | 0 | 3525.26 | 0 | 769.32 | 0 | 2000 | 0 | 0 | 0 |
| Soybean/irrigated | 2445.09 | 0 | 5341.28 | 0 | 2035.28 | 0 | 0 | 0 | 0 | 0 |
| Soybean/rain-fed | 0 | 0 | 4325.37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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